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Estimation of the Impact of Climate Change on Spinach Cultivation Areas in Türkiye

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Abstract: Climate change is one of the most important problems that needs to be dealt with in Türkiye and worldwide. One of the sectors that will be most affected by climate change is the agriculture sector. For this reason, it is very important to adapt to changing climatic conditions, take the necessary precautions, and ensure sustainability in the agricultural sector today. The land suitability for spinach (*Spinacia oleracea* L.) cultivation, a vegetable that is rich in nutrients, has never been investigated in Türkiye. Therefore, it is important to investigate the suitability of spinach cultivation areas in Türkiye in the case of possible climatic changes in future years. The most important original value of this research is that three separate climate change prediction models were used, as opposed to using only a single climate change prediction model, to determine the land suitability for spinach cultivation. The aim of this study is to determine the land suitability for spinach in line with possible climate change prediction models and scenarios in Türkiye and its evaluation by comparing it with the current model. To achieve this goal, HADGEM2_ES, CNRM_CM5, and MPI_ESM_LR climate models and RCP 4.5 and RCP8.5 scenarios were used, and land suitability was determined and evaluated with the help of Ecocrop integrated into DIVA-GIS for spinach in Türkiye currently and in the 2050s. The results found that there will be decreases in suitable, very suitable, and excellent areas for spinach cultivation and increases in not-suited, very marginal, and marginal areas. Considering the possible temperature and precipitation changes, it has been observed that the areas in which spinach can be grown in Türkiye in the 2050s will be negatively affected by climate change due to the increasing temperature and decreasing precipitation in general, and solutions are proposed in this study to ensure sustainability.

Keywords: climate models; DIVA-GIS; Ecocrop; *Spinacia oleracea* L.; suitability; sustainability

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1. Introduction

Climate change is a threat that we are trying to cope with both in Türkiye and globally. Determining the unknown effects of climate change and taking measures against known effects have become the greatest goals [1]. It is predicted that precipitation distribution and amount and temperature values will change significantly with climate change. It is estimated that many sectors will be affected by this change. Therefore, studies should be carried out at the local, regional, national, or international level to reduce and prevent the effects of climate change on sectors. In each region, actors in different sectors must know what precautions they need to take within their scope of work and must take them [2].

The agricultural sector is one of the sectors most affected by climate change in terms of product productivity, product pattern, decreasing water resources, increasing temperature, and food security. Therefore, it is necessary to ensure adaptation to changing climate conditions in the agricultural sector today [3].

Due to its geographical, climatic, and socioeconomic vulnerabilities to the effects of climate change and other environmental disasters, Türkiye places a strong priority on adaptation and resilience. Compared to other OECD (Organization for Economic Co-operation and Development) nations, Türkiye has high sensitivity in 9 out of 10 climate vulnerability dimensions [4]. According to the climate change projections for Türkiye, the temperature increase in Türkiye by 2100 is 3.4 °C according to the RCP4.5 scenario, and according to the RCP8.5 scenario, it can reach up to 5.9 °C. Temperatures are projected to increase throughout the century, starting from Türkiye's southern latitudes and expanding northward. Precipitation projections for the RCP4.5 and RCP8.5 scenarios using the HADGEM2-ES, MPI-ESM-MR, and CNRM-CM5.1 models show that depending on the earth system models, regional increases and decreases in precipitation will occur during the projection period (2015–2100). Model simulations predict that the climate regime in the basins located in northern Türkiye will be wetter than that in the reference period. For example, the RCP8.5 scenario reveals that the drought in the basins will intensify from the north to the south starting in the 2050s, and the ten-year average total annual precipitation on the basin will decrease to 150 mm [5]. As a result of constantly changing climatic conditions, ecosystem-oriented production should be continued by keeping the agriculture sector strong and protecting it from the negative effects of climate change, raising the awareness of all stakeholders in accordance with international conventions, and achieving agreements on climate change adaptation and mitigation [3].

In Türkiye, as one of the countries that will be most affected by climate change, it is necessary to know which plants will be most affected by climate change and where they should be grown, as this will enable the agricultural sector to take precautions. In other words, it is very important to determine the suitable and unsuitable areas to determine whether the suitable areas will increase or decrease or how they will change. When the studies conducted around the world were evaluated, it was found that the land suitability for spinach cultivation, which is a vegetable that is rich in nutrient content, was not investigated in Türkiye. Worldwide, only a few studies have been conducted. Therefore, it is important to investigate the suitability of spinach cultivation areas in Türkiye in future years. In addition, the most important difference that distinguishes this study from other studies is that three separate climate change prediction models were used, as opposed to using only a single climate change prediction model, to determine the land suitability for spinach cultivation. In this study, the suitability for spinach cultivation was analyzed by using Ecocrop integrated into DIVA-GIS. Therefore, we attempted to determine spinach plant suitability with Ecocrop for the first time in Türkiye. When unpredictable situations arise with climate change, being able to accurately predict spinach-planting areas, as spinach has an important place in the agriculture and food sector, will guide producers, decision-makers and practitioners.

In this context, studies have been carried out to determine the suitability of land against climate change for various plants worldwide and in Türkiye. Studies have been carried out worldwide on tomato, bean, sugar beet, carrot, chick pea, cowpea, eggplant, faba bean, grass pea, potato, sweat potato, common bean, broad bean, table potatoes, asparagus, cauliflower, broccoli, kale, white cabbage, celeriac, onions, parsnip, root parsley, leek, beet, red cabbage, lettuce, savoy cabbage, spinach, sweet corn, peas, jerusalem artichoke, leaf parsley, pumpkin, etc., to determine the suitability of land [6–22]. In Türkiye, suitable areas have been determined only for maize, safflower, canola (rape), cotton, wheat, switchgrass [23], and bioenergy crops [24].

Spinach is among the most consumed winter vegetables in Türkiye and worldwide. It is an extremely important vegetable in terms of both nutrition and vitamins. The annual production of spinach, which is widely cultivated worldwide, is 30 million tons, and China ranks first with a production of 27,527,619 tons. Türkiye ranks fourth worldwide after the USA (435,721 tons) and Japan (226,865 tons) in spinach production (229,793 tons) [25]. Spinach is grown very limitedly only in the Eastern Black Sea Region in Türkiye, which receives heavy rainfall. Spinach is a cultural plant that can be grown in all other regions. In 2020, spinach production in Türkiye was 231,515 tons, with the Aegean Region ranking first with 78,438 tons, followed by the Central Anatolia Region with 45,000 tons, the Black Sea Region with 29,874 tons, the Marmara Region with 27,545 tons, and the Mediterranean Region with 22,000 tons [26]. Therefore, it is very important to be able to determine how the areas in which spinach can be grown in Türkiye may be affected by future climate change, which will have an important impact on spinach cultivation. At the same time, spinach cultivation and vegetable diversity in Türkiye need to be sustained.

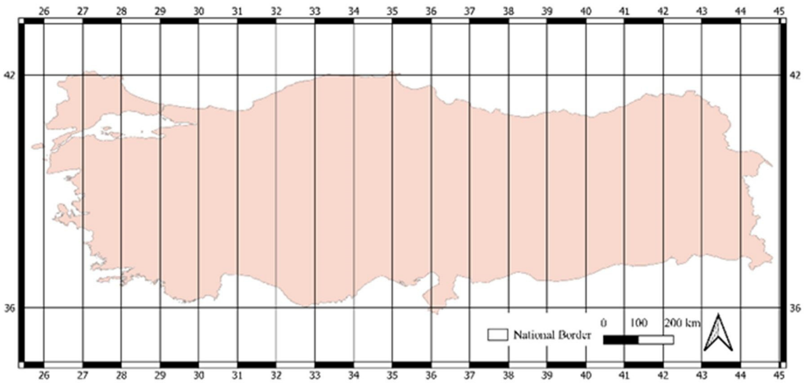
The aim of this study is to determine the current plant suitability for spinach in Türkiye with the help of Ecocrop and to determine and compare future plant suitability by using the CNRM_CM5 (National Centre for Meteorological Research—Climate Model, version 5), HADGEM2_ES (Hadley Centre Global Environmental Model, version 2 Earth System), and MPI_ESM_LR (Max Planck Institute Earth System Model—Low Resolution) climate models on the RCP4.5 and RCP8.5 (RCP: Representative Concentration Pathway) scenarios in the 2050s. Thus, the sensitivity of spinach cultivation areas to possible climate change will be determined, and suggestions will be presented to reduce the negative effects of climate change.

2. Materials and Methods

2.1. Research Area

Türkiye is located between 26° and 45° east longitudes and 36° and 42° north latitudes. The country has an area of approximately 780,000 km^2. Three percent of Türkiye's surface area is on the European continent (Thrace), while the rest is on the Asian continent (Anatolia). Türkiye has borders with Greece and Bulgaria to the west, Georgia, Armenia, Azerbaijan/Nakhichevan, and Iran to the east, and Syria and Iraq to the south [27]. The research area is shown in Figure 1. According to the data from the Turkish Statistical Institute for 2021, the total agricultural area was 38,063 thousand hectares (including grassland and pastureland). Of the total agricultural area, 52.2% was cultivated land, 9.4% was land with long-lived plants (perennial orchards), and 38.4% was permanent grassland and pastureland [28].

(a)



(b)

Figure 1. (**a**) Location of the research area [29], (**b**) Türkiye map.

2.2. Climate of the Research Area

Türkiye's climate is characterized by a semiarid climate. Türkiye is surrounded on three sides by the Mediterranean Sea, the Black Sea, and the Aegean Sea. The elevation of the high mountain ranges along the coast varies. Elevations increase from west to east, and their distance from the shore changes. Therefore, winds, precipitation, and temperature in Türkiye differ according to the region and time. The area east of the Black Sea has the highest rainfall (1200–2500 mm/year). Central Anatolia (around Salt Lake) has the least rainfall (250–300 mm/year). In addition to the coastal settlements of the Mediterranean and southern Aegean regions of Türkiye, snowfall is observed during the winter months [27]. The average temperature of Türkiye between 1970 and 2022 was 13.3 °C [30], the annual total precipitation average was 597.9 mm [31], the average of the maximum temperatures was 19.2 °C [32], the minimum average temperature was 7.9 °C [33], and the average relative humidity was 63.5% [34].

2.3. Climate Data Source

Current climate data were obtained from the website https://www.diva-gis.org/climate (accessed on 11 January 2023). These data are altitude, minimum temperature, maximum temperature, mean temperature, and precipitation data with a resolution of 2.5 min covering the period 1950–2000. The source of these data is the website (https://www.worldclim.org/, accessed on 13 December 2022) [35]. Data covering the future projection were downloaded from the CCAFS (http://www.ccafs-climate.org/, accessed on 30 March 2023) [36]. The data are the minimum temperature, maximum temperature, and precipitation data with a resolution of 2.5 min covering the RCP4.5 and RCP8.5 scenario results of the CNRM_CM5, HADGEM2_ES, and MPI_ESM_LR climate models.

2.4. Crop Suitability Model: Ecocrop

Ecocrop is a database that contains information on approximately 2568 plant species [37]. The Ecocrop model is a mechanistic tool used to predict land suitability for various plants. Integrated into the DIVA-GIS software (Version 7.5.0.0), Ecocrop considers only temperature and precipitation to determine plant suitability [38,39]. The parameters used by Ecocrop are the minimum length of the growing season (Gmin), maximum length of the growing season (Gmax), killing temperature during rest (KTmp), minimum temperature (Tmin), maximum optimum temperature (TOPmax), minimum optimum temperature (TOPmn), maximum temperature (Tmax), minimum precipitation (Rmin), maximum precipitation (Rmx), minimum optimum precipitation (ROPmn), and maximum optimum precipitation (ROPmx). A detailed description of the Ecocrop model is provided by Joshi [19], Ramirez-Villegas et al. [40], Labaioui and Bouchoufi [41], and Wichern et al. [42]. The suitability index ranges from 0 to 100 in Ecocrop, and the classifications are as follows: 0% is not-suited, 1–20% is very marginal, 21–40% is marginal, 41–60% is suitable, 61–80% is very suitable, and 81–100% excellent.

2.5. Spinach (*Spinacia oleracea* L.)

Spinach is an annual, herbaceous, cool-climate vegetable produced by seed. It is a vegetable grown by sowing the seed directly into the ground. Spinach is a root crop. Pile roots reach a depth of 15–20 cm in normal agricultural soils. Spinach shows optimum growth at temperatures of 16–18 °C. It is possible to successfully cultivate spinach in places where the average temperature is approximately 10 °C. Spinach is rich in few minerals, mainly iron and potassium. The main importance of spinach is the vitamins it contains: it is rich in vitamins A and C and contains folic acid. Yield in spinach varies between 1.5 and 3 tons/da [43]. The Ecocrop parameters for spinach are shown in Table 1 [44].

Table 1. Crop growth thresholds for spinach as generated by the Ecocrop model [44].

Crop Growth Thresholds	FAO Ecocrop Parameters for Spinach
Minimum length of the growing season (Gmin)	40 days
Maximum length of the growing season (Gmax)	120 days
Killing temperature (KTmp)	−7 °C
Minimum temperature (Tmin)	2 °C
Minimum optimum temperature (Toptmin)	13 °C
Maximum optimum temperature (Toptmax)	20 °C
Maximum temperature (Tmax)	27 °C
Minimum precipitation (Rmin)	300 mm
Minimum optimum precipitation (Roptmin)	800 mm
Maximum optimum precipitation (Roptmax)	1200 mm
Maximum precipitation (Rmax)	1700 mm

2.6. Method

In the research, first, the data were obtained from the website https://www.diva-gis.org/climate (accessed on 11 January 2023), regarding the current climate data of the 1950–2000 period [45]. Then, the climate data of the RCP4.5 and RCP8.5 scenarios according to the CNRM_CM5, HADGEM2_ES, and MPI_ESM_LR global climate models for the future (2050s) period were obtained from http://www.ccafs-climate.org (accessed on 30 March 2023) [36]. After that, these climatic data were mapped and evaluated. Second, using the Ecocrop database integrated into the DIVA-GIS 7.5 [46] software, a current plant suitability map for the 1950–2000 period was created for spinach. Then, plant suitability prediction maps were created by evaluating the RCP4.5 and RCP8.5 scenario results of the CNRM_CM5, HADGEM2_ES, and MPI_ESM_LR global climate models for the future period. Finally, these created maps were analyzed using QGIS (Quantum GIS) version 3.28.3 [47]. The results were evaluated by comparing the current and future maps obtained.

3. Results

3.1. Evaluation of Climate Data

In the first stage of the study, climate data were evaluated. The average temperatures increased according to the results of the CNRM_CM5, HADGEM2_ES, and MPI_ESM_LR climate models for the RCP4.5 and RCP8.5 scenarios. These increases were 1.8–2.4 °C in the CNRM_CM5 model, 3.1–4.0 °C in the HADGEM2_ES model, and 1.9–3.1 °C in the MPI_ESM_LR model in the 2050s compared to the current values (Table 2). These temperature changes will be observed more in RCP8.5 than in RCP4.5; this is expected because RCP8.5 is a more pessimistic scenario than RCP4.5. In Figure 2, current, CNRM_CM5, HADGEM2_ES, and MPI_ESM_LR climate model temperatures for the RCP4.5 and RCP8.5 scenarios and the temperature difference maps between the current values and those of the models are shown. At the same time, the average temperature values seen in Table 2 are shown on the right in Figure 2 as the difference between current average temperatures and future average temperatures. The variation in the mean temperature difference is displayed in different colors according to the amount of change.

Table 2. Current (1950–2000) and future (2050s) temperature and precipitation values.

Current and Climate Change Prediction Models	Annual Temperature (°C)			Precipitation (mm)		
	Minimum	Maximum	Average	Minimum	Maximum	Average
Current	−4.1	19.6	10.8	254	2009	594
CNRM_CM5 RCP4.5	−2.1	21.5	12.6	278	2212	596
CNRM_CM5 RCP8.5	−1.5	22.3	13.2	274	2296	577
HADGEM2_ES RCP4.5	−0.1	23.0	13.9	229	2244	560
HADGEM2_ES RCP8.5	0.8	24.0	14.8	217	2248	573
MPI_ESM_LR RCP4.5	−1.4	22.0	12.7	173	2135	504
MPI_ESM_LR RCP8.5	−0.3	23.2	13.9	215	2093	497

When the annual precipitation is evaluated in this study, it is seen that precipitation will vary according to the results of the CNRM_CM5, HADGEM2_ES, and MPI_ESM_LR climate models for the RCP4.5 and RCP8.5 scenarios, and the precipitation difference maps between current and the estimated values are plotted (Figure 3). In the CNRM_CM5 model, the average precipitation in the 2050s increased by 2 mm in RCP4.5 and decreased by 17 mm in RCP8.5 compared to the current values. For the HADGEM2_ES model, the average precipitation decreased by 34–21 mm in RCP4.5 and in RCP8.5, and for the MPI_ESM_LR model, the average precipitation decreased by 90–97 mm in RCP4.5 and in RCP8.5 (Table 2). At the same time, the annual precipitation values seen in Table 2 are shown on the right in Figure 3 as the difference between current annual precipitation and future annual precipitation. The variation in the annual precipitation difference is displayed in different colors according to the amount of change.

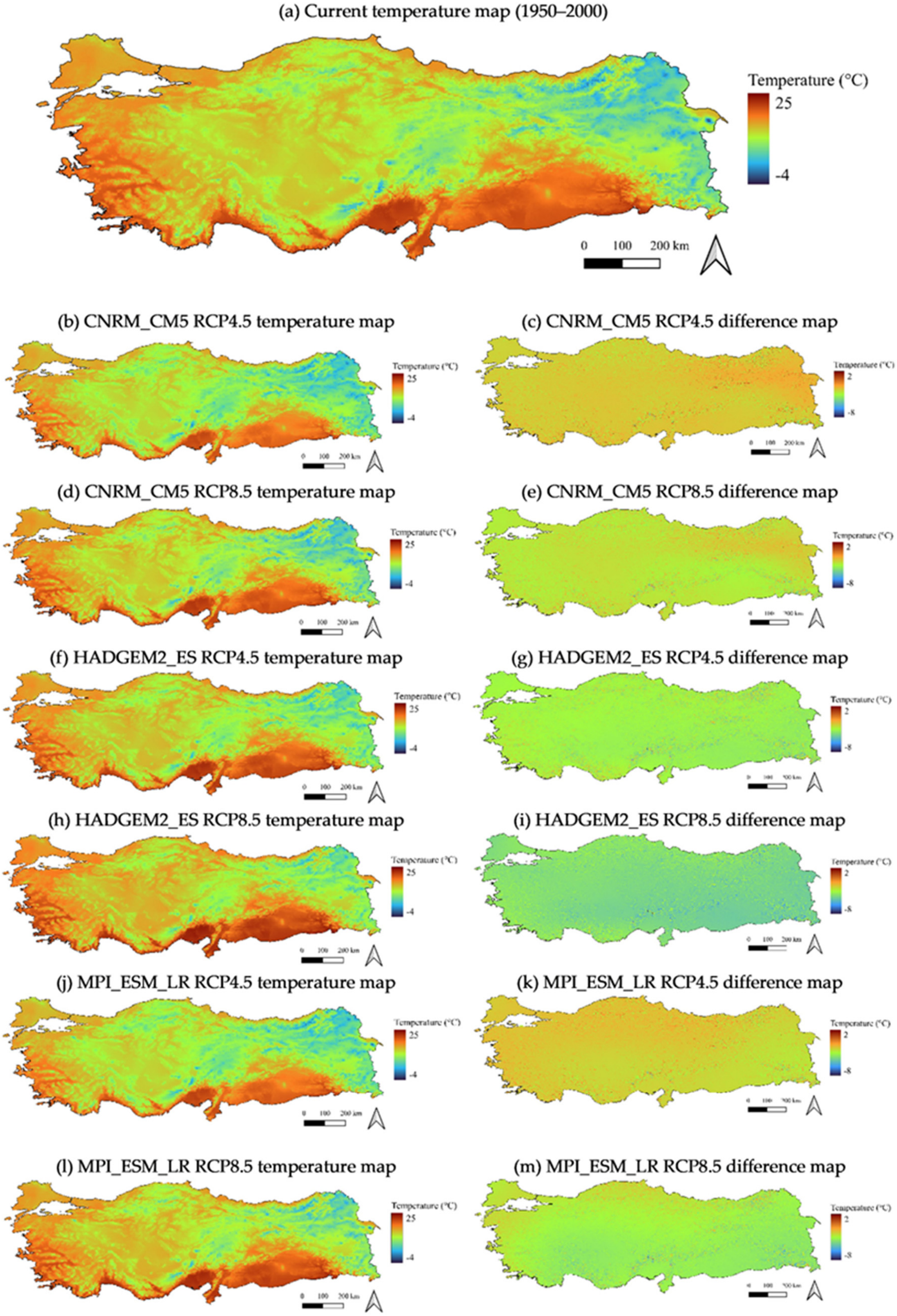


Figure 2. Current (1950–2000), future (2050s), and changed (future temperature map difference from current temperature map) annual mean temperature maps.

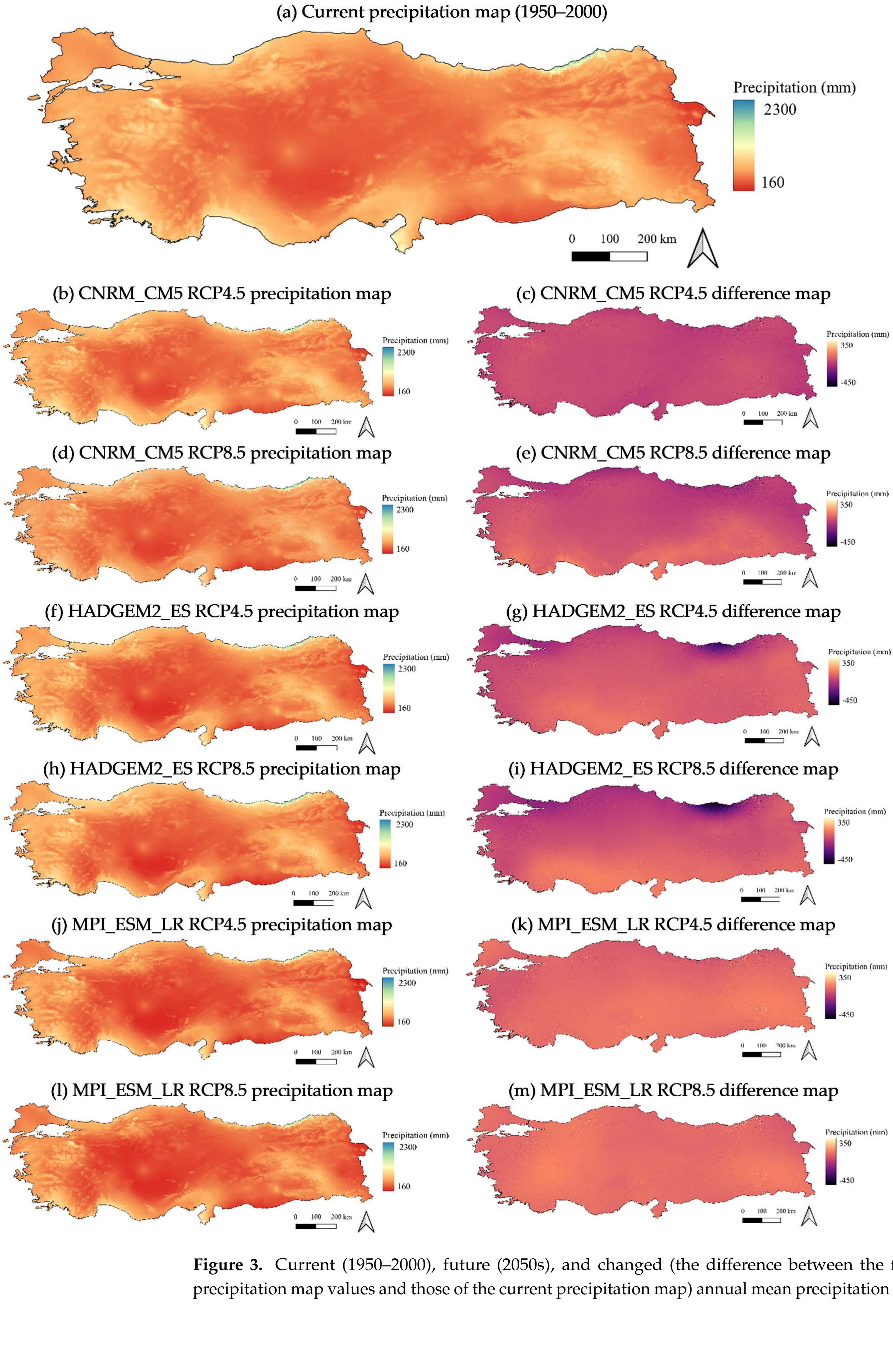


Figure 3. Current (1950–2000), future (2050s), and changed (the difference between the future precipitation map values and those of the current precipitation map) annual mean precipitation maps.

3.2. Evaluation of Suitability

The RCP4.5 and RCP8.5 scenario results of the CNRM_CM5, HADGEM2_ES, and MPI_ESM_LR global climate models were evaluated by estimating the suitability of spinach cultivation areas in the 2050s. Suitability maps are shown in Figure 4.

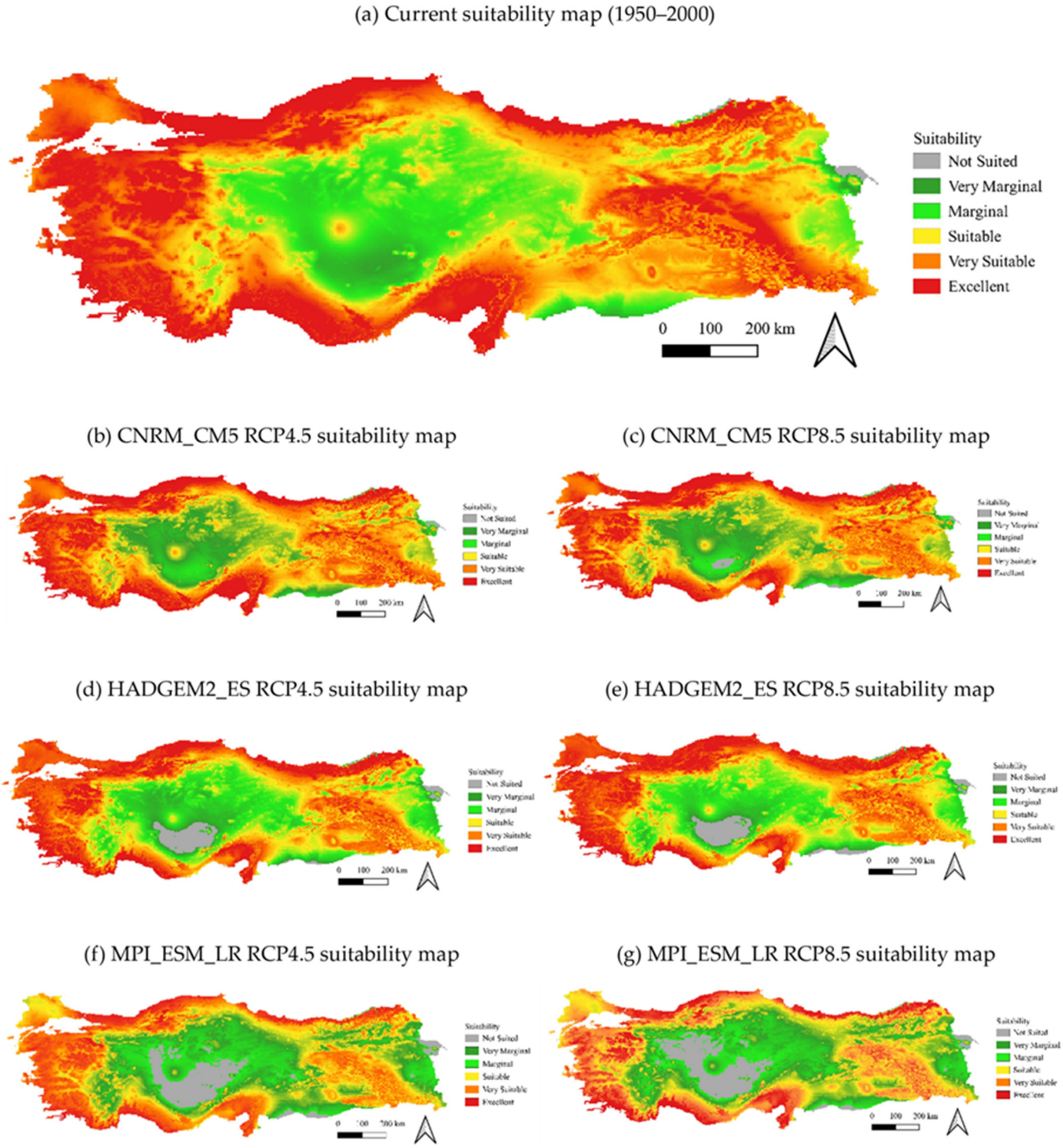


Figure 4. Current (1950–2000) and future (2050s) suitability maps for spinach.

When Figure 4a–c are compared, it is noticeable that there is not much change in CNRM_CM5 for RCP4.5; that is, in Figure 4b, there is not much change compared to the current values, and the excellent areas decreased. Compared to the current values, the significant change in CNRM_CM5 for RCP8.5 in Figure 4c is that the excellent areas are reduced more than in Figure 4b, and a small not-suited region is formed in the central part of Türkiye. These changes can be explained as follows. When the temperature change with precipitation is compared according to Table 2, it is seen that the parameter that is effective in the change in the suitability maps in Figure 4a,b is temperature. A further increase in temperature in CNRM_CM5 for RCP8.5 affected the spinach cultivation areas more negatively in this model and scenario. This temperature change is clearly visible in Figure 2c,e. The precipitation change in Figure 3e is very slightly reflected in Figure 4c, affecting southern Türkiye and resulting in very little tonal variation. However, it is acceptable for temperature change to significantly affect the suitability maps.

When Figure 4a,d,e are compared, it is noticeable that while the excellent and suitable areas decreased, the not-suited and very marginal areas increased in HADGEM2_ES for RCP4.5 and RCP8.5. According to Table 2, when the change in temperature is compared with the change in precipitation, it seems that temperature is the effective parameter in the change seen in the suitability maps in Figure 4d,e; this is because Figure 3g,i are almost the same tone. This is calculated in Table 2 as a decrease of 34–21 mm, which is only a small change. When the maps in Figure 2g,i are examined, it is seen that the color tones are different. Table 2 shows that the temperature differences between the current values and those of HADGEM2_ES for RCP4.5 and RCP8.5 are 3.1–4.0 °C. This difference is the largest difference between the models in this study.

When Figure 4a,f,g are compared, it is observed that excellent, very suitable, and suitable areas decreased and that not-suited and very marginal areas increased in MPI_ESM_LR for RCP4.5 and RCP8.5 compared to the current values. When the temperature change with precipitation is compared according to Table 2, it is understood that both temperature and precipitation are the parameters that affect the change in the suitability maps in Figure 4f,g; this is because Figure 2k,m have markedly different tones. This situation appears as a temperature difference of 1.9–3.1 °C in MPI_ESM_LR for RCP4.5 and RCP8.5 from Table 2 to the current values. Examining the maps in Figure 3k,m show that they are quite different in tone compared to the maps in Figure 3c,e,g,i. This is because, as shown in Table 2, there is a decrease in precipitation of 90–97 mm in MPI_ESM_LR for RCP4.5 and RCP8.5 compared to the current values. Therefore, the further decrease in precipitation and increase in temperatures caused the largest decreases in the maps in Figure 4f,g.

The three models were compared with each other. Very marginal areas increased in the future in the CNRM_CM5 climate model, and not-suited and marginal areas decreased in RCP4.5 and increased in RCP8.5. Suitable and very suitable areas increased in RCP4.5 and decreased in RCP8.5. Excellent areas decreased in both scenarios (Figure 5).

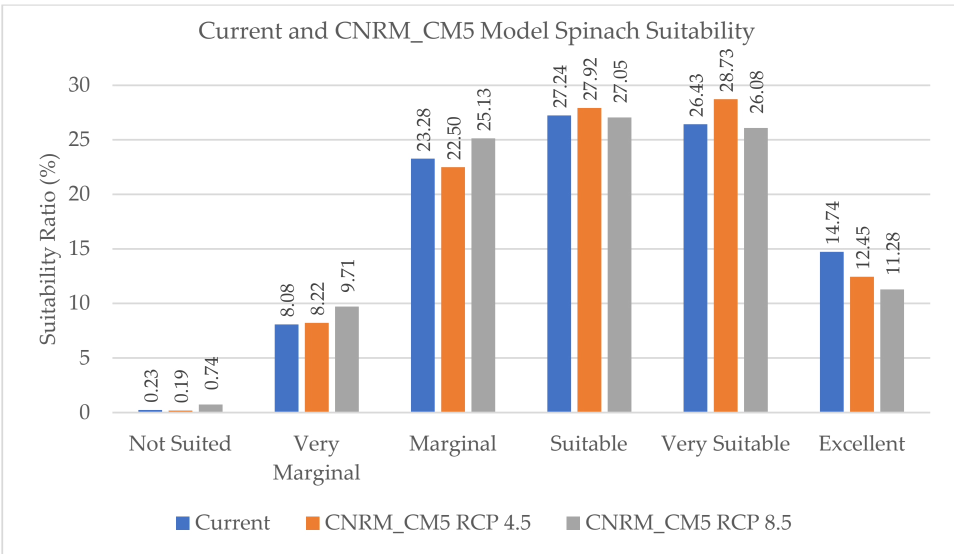


Figure 5. Suitability assessment results of spinach under the RCP4.5 and RCP8.5 scenarios according to the CNRM_CM5 model for the current and future periods (2050s).

When the results of the HADGEM2_ES climate model for the current and future (2050s) RCP4.5 and RCP8.5 scenarios are evaluated, it is found that not-suited and very marginal areas increased in the future. Marginal areas decreased in RCP4.5 and increased in RCP8.5, suitable and excellent areas decreased in both scenarios, and very suitable areas increased in both scenarios (Figure 6).

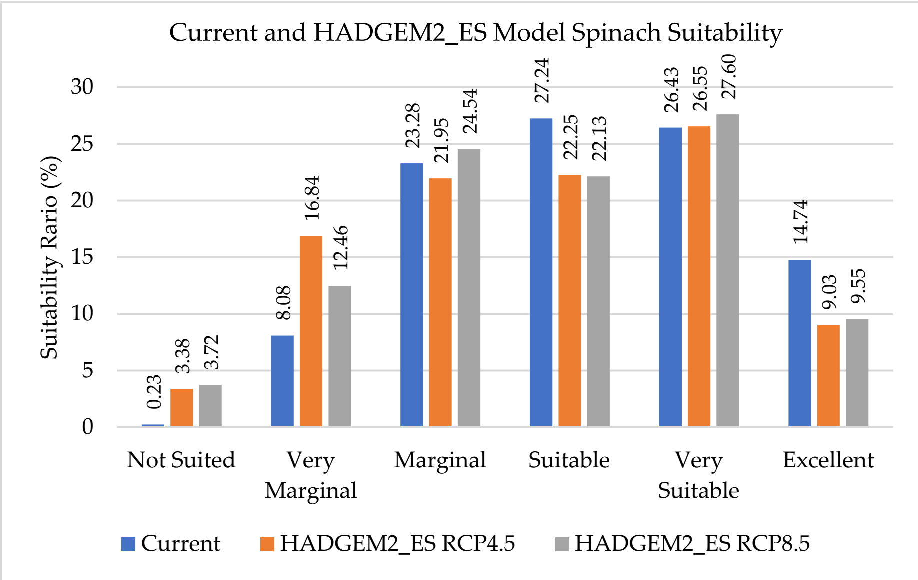


Figure 6. Suitability assessment results of spinach under the RCP4.5 and RCP8.5 scenarios according to the HADGEM2_ES model for the current and future periods (2050s).

When the MPI_ESM_LR climate model results for the current and future (2050s) RCP4.5 and RCP8.5 scenarios were evaluated, it is seen that not-suited and very marginal areas increased in the future, marginal areas decreased in RCP4.5 and increased in RCP8.5, and suitable, very suitable, and excellent fields decreased in both scenarios (Figure 7).

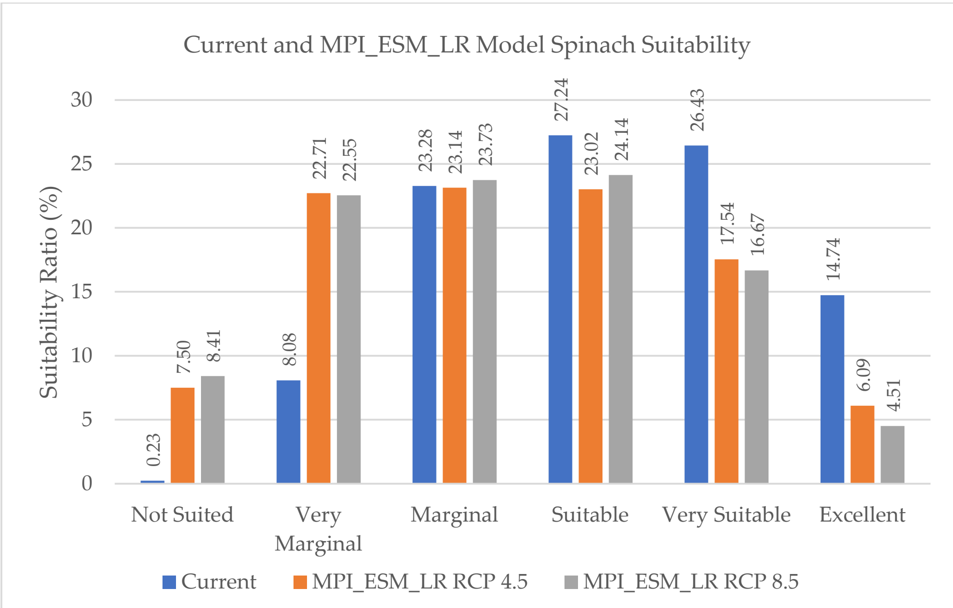


Figure 7. Suitability assessment results of spinach under the RCP4.5 and RCP8.5 scenarios according to the MPI_ESM_LR model for the current and future periods (2050s).

In Figure 8, the RCP4.5 and RCP8.5 scenario results with the CNRM_CM5, HADGEM2_ES, and MPI_ESM_LR global climate models for the current and future periods are compared with the plant suitability estimates. In not-suited areas, there was an increase of up to 8.41% in all models and scenarios except in CNRM_CM5 for RCP4.5 compared to the current value (0.23%). Very marginal areas increased in all models.

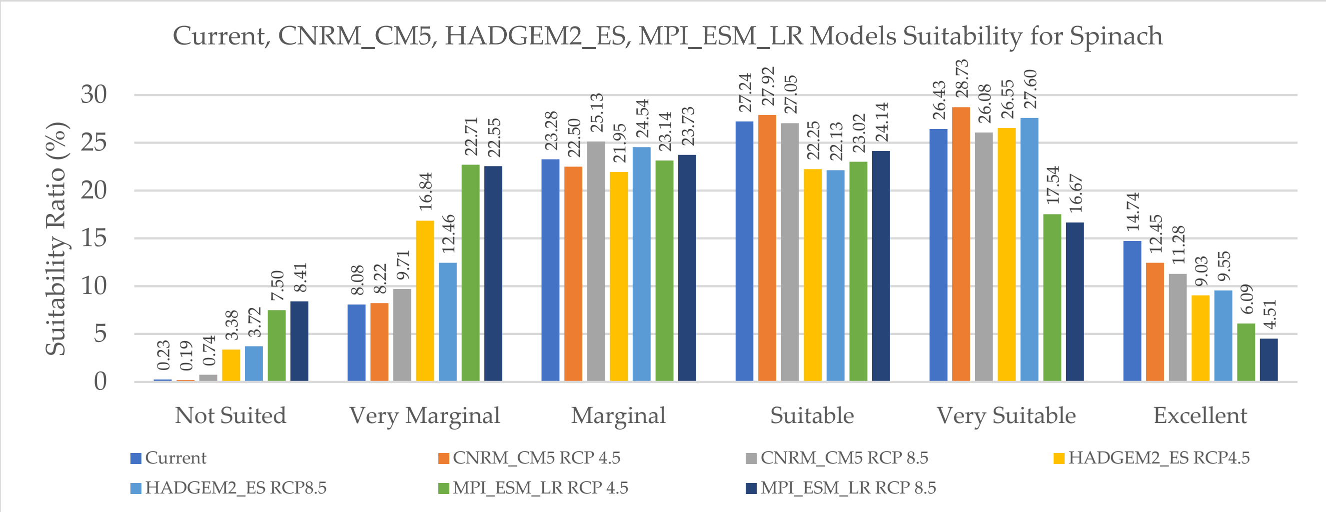


Figure 8. Suitability assessment results of spinach under the RCP4.5 and RCP8.5 scenarios according to CNRM_CM5, HADGEM2_ES, and MPI_ESM_LR climate models for the current and future periods (2050s).

The largest variation in marginal areas was estimated to be from 8.08% (current) to 22.71% in MPI_ESM_LR for the RCP4.5 scenario. There were increases and decreases in values close to each other in all models and scenarios in marginal areas. Only CNRM_CM5 and RCP4.5 showed increase in suitable areas and decrease in others. There have been increasing and decreasing changes in very suitable areas. For the excellent areas, the changes were clearly in a decreasing direction. The largest change was in very suitable areas (28.73%) in CNRM_CM5 for RCP4.5, while the smallest change was in not-suited areas (0.19%) in the same model and scenario.

Finally, in Figure 9, the averages of the 2050s results of the HADGEM2_ES, MPI_ESM_LR, and CNRM_CM5 global climate models are shown. The RCP4.5 and RCP8.5 scenario result averages were separately evaluated for land suitability. Not-suited areas increased from 0.23% to 3.7% in RCP4.5 and 4.3% in RCP8.5 compared to the current value, and very marginal areas increased from 8.08% to 15.9% in RCP4.5 and 14.9% in RCP8.5. Marginal areas decreased from 23.28% to 22.5% in RCP4.5 and increased to 24.5% in RCP8.5 compared to the current value. On the other hand, suitable areas decreased from 27.24% to 24.4% in RCP4.5 and RCP8.5 compared to the current value, and very suitable areas decreased from 26.43% to 24.3% in RCP4.5 and 23.4% in RCP8.5. Excellent areas also decreased from 14.74% to 9.2% in RCP4.5 and 8.4% in RCP8.5 compared to the current value. According to these results, there will be significant increases in not-suited and very marginal areas and significant decreases in suitable, very suitable, and excellent areas. In marginal areas, decreases in RCP4.5 and increases in RCP8.5 are predicted for all model averages.

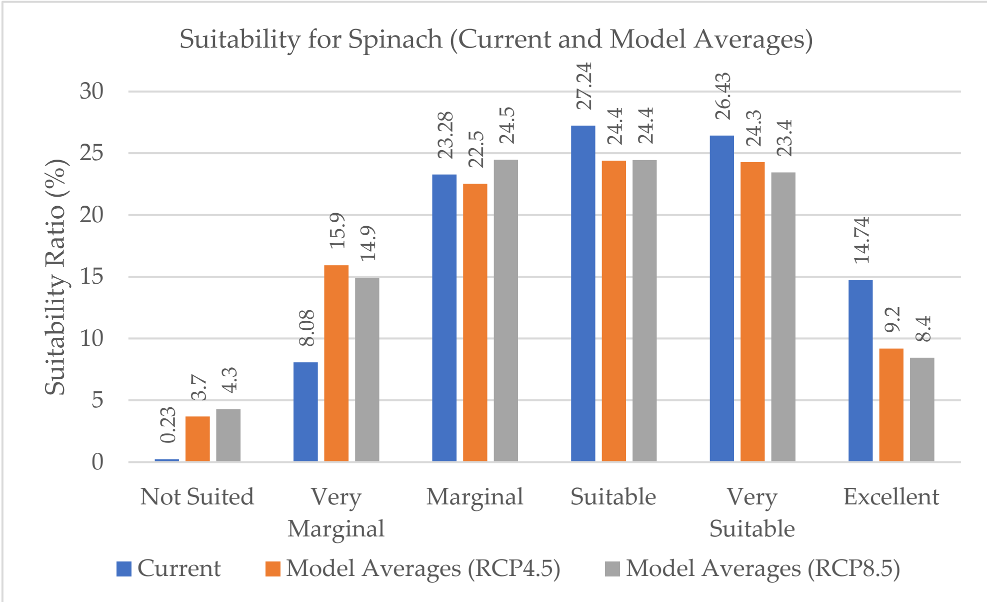


Figure 9. The average of the scenarios according to suitability assessment results of spinach for the CNRM_CM5, HADGEM2_ES, and MPI_ESM_LR climate models for the current and future periods (2050s).

4. Discussion

In Türkiye, the "Impact of Climate Change on Water Resources" project was carried out between 2013 and 2016 by the Ministry of Forestry and Water Affairs, General Directorate of Water Management. In this project, the HADGEM2_ES, MPI_ESM_MR, and CNRM_5.1 climate models were evaluated according to the results of the RCP4.5 and RCP8.5 scenarios between 2015 and 2100. It has been estimated that temperatures would continue to increase linearly. According to the HADGEM2_ES model, between 2041 and 2070, it is predicted that annual average temperatures will increase up to 3 °C, and starting in the 2040s, there will be an increase of 3–5 °C, especially in summer temperatures. The average temperature anomaly values of all three models will give positive results for all four seasons compared to the reference period. Therefore, this situation was evaluated as indicating significant warming in Türkiye [5]. The temperature results found in this study also confirm this project.

In the results of the "Impact of Climate Change on Water Resources" project, it is predicted that there will be changes between −50 mm and 40 mm for the RCP4.5 scenario and between −60 mm and 20 mm for the RCP8.5 scenario in the ten-year seasonal precipitation averages during the 2015–2100 projection period [5]. Therefore, similar results were observed with the precipitation intervals of the project results with our study using the HADGEM2-ES and CNRM_CM5 models. However, in the results of the MPI_ESM_LR model with the RCP4.5 and RCP8.5 emission scenarios, precipitation increases of 90–97 mm are predicted. It is possible to explain the differences in the results as follows. The MPI_ESM_MR model was used in the project, whereas the MPI_ESM_LR model was used in this study. Because the models are different, finding the same results may not be expected. Similar results were obtained in the HADGEM2-ES and CNRM_CM5 models in both studies, and the results support each other.

As a result, according to the "Impact of Climate Change on Water Resources" project, it is predicted that temperature increases will continue throughout the projection period according to all three models and both scenarios between 2015 and 2100. It is estimated that the HADGEM2_ES model will reach approximately 3.5 °C for the RCP4.5 scenario and approximately 6 °C for the RCP8.5 scenario. The MPI_ESM_MR model will reach approximately 2 °C for the RCP4.5 scenario and approximately 4 °C for the RCP8.5 scenario.

The CNRM_CM5.1 model will reach approximately 2.4 °C for the RCP4.5 scenario and approximately 4.1 °C for the RCP8.5 scenario. In terms of annual precipitation, a decrease is expected in total precipitation amounts between 2015 and 2100 in Türkiye according to both scenarios. It is predicted that there will be more significant reductions of 250–300 mm (60 mm on average) from 2050 onward [5]. This study predicts increases in temperatures in the 2050s compared to the current temperatures; it found decreases in precipitation in the CNRM_CM5 model for RCP8.5, and HADGEM2_ES model for RCP4.5 and RCP8.5 scenarios, and MPI_ESM_LR model for RCP4.5 and RCP8.5 scenarios and found only a 2 mm increase in RCP4.5 in the MPI_ESM_LR model. The reason for this was also explained, and this increase was considered normal. Therefore, the results of HADGEM2_ES and CNRM_CM5 models' climate change are in harmony with "Impact of Climate Change on Water Resources" project results.

When suitability estimates are made in the areas with spinach cultivation in the 2050s, it has been determined that there will be decreases in suitable, very suitable, and excellent areas, and there will be increases in not-suited, very marginal, and marginal areas in general in the future compared to current values. Therefore, when the impact of climate change on the areas where spinach is grown in Türkiye in the 2050s is evaluated, it is estimated that spinach cultivation will be adversely affected. It is estimated that this situation will be caused by increases in temperatures and decreases in precipitation. It has been reported that for leafy vegetables such as spinach, drought will cause reduced water content in the plant, resulting in lower quality and yield [48]. Schlering et al. [49] stated that the leaf development of plants such as spinach is highly dependent on water availability and that spinach is sensitive to water. In addition, Hong et al. [50] stated that spinach has a high sensitivity to water security amidst climate change. Therefore, it was considered possible that the suitability of spinach, which is a water-sensitive plant, would decrease as precipitation decreases. At the same time, considering that saline areas are increasing because of global warming and changes in precipitation regimes [51], it is thought that salt stress in plants may have a significant negative effect on yield and quality [52]. Deveci and Tuğrul [53] obtained supportive results in their study on salinity in spinach. Increasing temperatures cause changes in the vegetation periods of plants. With the increase in temperature, the length of the growing season in Türkiye has increased by an average of 21 days per century. At the same time, plant growth and development periods are also affected by temperature increase [54]. Prasad and Chakravorty [55] stated that the cultivation of vegetables under different agro-climatic factors will vary significantly. They noted that any deviation due to climate change could cause unprecedented stress on vegetables. They commented that this stress could lead to complete failure of the grower in his field. Another factor affecting plant growth and development is CO_2. In the scenarios used in this study, it is assumed [56] that CO_2 concentration will reach 650 ppm by 2100 in the RCP4.5 scenario and that it will reach and exceed 1370 ppm in the RCP8.5 scenario. Bisbis et al. [57] stated that any increase in CO_2 reduces the number of macro-microelements and decreases product quality. In this study, more negative suitability maps were formed in all three models based on the RCP8.5 scenario results than those formed based on the RCP4.5 scenario results. Thus, these results are in agreement with one another. In addition, by growing a seed in the same place every year, the productivity and durability of that seed, as well as the genetic characteristics of the seed, will decrease. If the seed characteristics of different plant varieties are not improved over time according to changing ecological conditions, economic problems may arise in vegetable cultivation and vegetable sustainability will be interrupted.

5. Conclusions

In general, when the results of the CNRM_CM5, HADGEM2_ES, and MPI_ESM_LR climate change prediction models in Türkiye for the 2050s were evaluated, it is estimated that there will be increases in temperatures and decreases in precipitation compared to the current conditions. When suitability estimates are made for the areas of spinach cultivation in the 2050s, there will be decreases in suitable, very suitable, and excellent areas, and there will be increases in not-suited, very marginal, and marginal areas in general in the future compared to the current situation. Therefore, when the impact of climate change on the areas in which spinach can be grown in Türkiye in the 2050s is evaluated, it is estimated that spinach cultivation will be adversely affected. With the Ecocrop model, only temperature and precipitation changes are taken into account in the estimation of plant suitability. When the impact of climate change on spinach cultivation in Türkiye is evaluated, since the areas where spinach can be cultivated will be negatively affected by climate change, all kinds of studies should be supported and encouraged to ensure the adaptation of spinach to climate change and sustainability. Spinach is an important vegetable in human nutrition. Spinach is a short-day and cool climate vegetable. Under conditions of increased temperature and long days, spinach starts to flower by passing from the vegetative phase to the generative phase. This means that this vegetable, whose leaves are eaten, starts to produce seeds under these conditions. Today, spinach is grown intensively in the spring and autumn, which we call the intermediate period. This may also mean that the spinach will shift to winter conditions by changing the seasons due to the possible increase in temperature in the future. Therefore, it is necessary to carry out research to develop and improve heat-resistant varieties and to increase plant suitability by changing the planting and harvesting calendar. Taking the necessary measures to improve suitability in the future and setting goals and strategies should become the ultimate goal.

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